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NANTICOKE TGS - TURBINE BLADE/DISC INVESTIGATION
3-D FINITE ELEMENT STRESS ANALYSIS

Report No 87-211-K

M.F. Ishac & T.P. Byrne
Applied Mechanics Section
Mechanical Research Department

ABSTRACT

This report summarizes the 3-D finite element stress analysis of the blade/disc attachment carried out as a part of the Nanticoke TGS - Turbine Blade/Disc Investigation. The objective of the analysis is to investigate the global mechanical behaviour of the blade/ disc attachment due to the centrifugal loading. It is a step towards understanding the mechanisms and causes of blade failure. The stress results indicate that the complex vane/root interaction (without the locking groove) is creating the high stresses at the locations of crack initiation.

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EXECUTIVE SUMMARY

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In November, 1983, the L-1 blade failure at the blade root top serration fillet of Nanticoke TGS Unit 2 resulted in a forced shut-down. Following this blade failure, two independent stress analysis investigations were carried out. One investigation by NEI Parsons was reported in 1984 and a second one by Ontario Hydro Research Division was reported in early 1985.

The recent discovery of cracks at new locations of the blade root in Unit 6 created a need to extend our previous investigation and create an improved finite element model to carry out a more detailed stress analysis throughout the blade and the disc. This finite element model included the vane, the platform, the blade root and disc, with no locking groove.

The stress analysis results show that high stresses exist at the locations of crack initiation. These stresses are primarily the result of the complex interaction between the vane and the blade root. They are not due to the locking groove.

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To Mr. T.J. Popiel
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NANTICOKE TGS - TURBINE BLADE/DISC INVESTIGATION
3-D FINITE ELEMENT STRESS ANALYSIS

1.0 INTRODUCTION

In November 1983, the L-1 blade failure at Nanticoke TGS Unit 2 blade root top serration fillet resulted in a forced shut-down. Twelve other blades in the same row were found to have blade root cracks. Two of them were cracked at the top serration fillet above the locking groove. The dominant origin of these cracks was 8 to 10 mm from the acute outlet end corner as shown in Figure 1.a.

Two independent stress analysis investigations were carried out following this blade failure. One investigation by NEI Parsons (1) was reported in 1984 and a second one by Ontario Hydro Research Division (2) was reported in early 1985.

Parsons' investigation considered two proposed modifications to the blade root (local reprofiling of the blade root as shown in Figure 1.b and completely removing the blade material immediately above the locking groove as shown in Figure 1.c). Parsons' report (1) concluded that local reprofiling will increase the top serration fillet stresses near the position of failure which was considered unacceptable. Their report identified the locking groove as the main cause of the highly localized stresses and suggested removing the blade material immediately above it. No analysis was carried out to support this "improved" condition.

The OHRD investigation considered a comparison between the three designs: 1) existing design (Figure 1.a); 2) first proposed modification (Figure 1.b); and 3) new improved modification (Figure 1.c). The conclusions drawn by the OHRD report (2) can be summarized as follows:

a) For the existing design, the maximum stresses occurred at the location of crack initiation.

b) For the first proposed modification, the maximum stresses were two times higher than those in the existing design.

c) For the new improved modification, the maximum stresses were 40% higher than those in the existing design.

d) Two locations of high stress were found along the top serration of the blade root.

In the fall of 1986, an inspection was performed on Unit 6 at Nanticoke TGS. Cracks at new locations on the blade root were observed. Blade root cracks were found near the leading edge of the root. Some shallow disc cracks were also found. Based on the findings of this inspection a few comments were raised:

a) The new cracks near the leading edge of the blade root were consistent with the stress results predicted by OHRD in the 1985 report (2).

b) The two locations of high stress predicted in the previous report (2) may be more a manifestation of the 3-D effects of the vane loading on the root rather than a stress concentration effect due to the locking groove.

The discovery of cracks at the new locations created a need for a more detailed investigation of the stresses throughout the blade and the disc. The purpose of the analysis described in this report is:

a) To locate other areas of high stress and therefore potential locations for crack initiation and failure.

b) To obtain a better understanding of the mechanisms that lead to these high stresses. This will help us to assess various modifications or "fixes".

In order to achieve the above two objectives, it was necessary to create an improved finite element model with the following features:

a) The model included the vane, platform, root and disc.

b) A finer mesh was used in areas away from the locking groove.

c) The boundary conditions were as realistic as possible.

d) The locking groove was not included in the model because of the vast size of the analysis. It was also of interest to determine if the high stresses would exist with no locking groove.

This report summarizes the results of the preliminary 3-D finite element stress analysis and draws some conclusions and recommendations.

2.0 FINITE ELEMENT ANALYSIS

The turbine blades are attached to the outer rim of the rotor disc by a mating of tree-shaped slots in the blade root and the rotor disc as shown in

Figure 2. The slots are skewed with respect to the rotor axis. In addition to the complex geometry, the analysis is made more difficult because of the severe and complex loading environment to which the blade is subjected.

Although it is recognized that some nonlinear behaviour such as creep and local plasticity are likely to occur, the present analysis only considers elastic behaviour. The assumption is also made that a perfect fit exists so that the "teeth" of the blade root and disc match perfectly at the contact surfaces. The serration fillet radii are assumed to be 0.76 mm (0.030 in) as per Parsons drawing No /136A/L101B Revision C.

2.1 3-D Finite Element Model

The 3-D finite element model consisted of a single disc groove segment along with a blade root, platform and aerofoil. Appropriate boundary conditions were applied to simulate the surrounding blades and disc. The geometry used to create the finite element model is shown in Figure 3. The 8-noded brick element was used in the modelling. The model of the blade root is shown in Figure 4 and the portion of the attachment region of the turbine disc is shown in Figure 5. The blade aerofoil shape is always plotted in the figures to differentiate between the leading edge and the trailing edge of the model. Patran II (3) was used to develop the finite element model.

Figure 6 shows the model for the blade root/disc assembly. The whole 3-D finite element model consists of 4360 brick elements and 6121 nodes. The general purpose structural analysis program ABAQUS (Version 4.5) was used to carry out the stress analysis. The post-processing of the stress analysis results was also performed using PATRAN II.

2.2 Loading and Boundary Conditions

In this analysis, only centrifugal loading was considered. This load was applied as a static body force with the amplitude dependent on the radial distance to the rotor axis and assuming a rotational speed of 3600 rpm.

The boundary conditions used in the modelling are summarized in the following:

a) Displacement was constrained at the bottom of the disc segment.

b) Rotation symmetry was used on each side of the disc segment (i.e. displacement is periodic).

c) A perfect fit between the blade root and disc groove serrations was assumed.

3.0 STRESS ANALYSIS RESULTS

3.1 Blade Root Serrations

The color-coded stress analysis results for the blade root are shown in Figures 7 to 11. The Von Mises stress intensities for one view are shown in

Figure 7.a and those for the opposite view are shown in Figure 7.b. The displacement results in the X, Y and Z directions are plotted in Figures 8 to 10, respectively.

The stresses in the critical areas can be determined by comparing the colors in these areas to the color-coded stress spectrum that appear along the right-hand edge of the plot. The largest stress occurring in the blade root is equal to the maximum stress given in the stress spectrum (i.e. 507 MPa). The maximum stress-range (red color) occurs at the first serration at three locations. Two locations are identified from Figure 7.a and one location is identified from the opposite view given in Figure 7.b.

The deformed shape of the blade root and platform due to centrifugal loading is shown in Figure 11. It is clear from this deformed shape and the stress results that the location of the areas of high stress are highly dependent on the way in which the forces from the aerofoil are transferred to the root. The shape of the aerofoil and the thickness of the platform are dominant factors when determining high stress areas.

3.2 Disc Groove Serrations

The stress analysis results for the disc groove are shown in Figure 12 to 15. The Von Mises stress intensities for one side of the disc segment are shown in Figure 12.a and those for the other side are shown in Figure 12.b. It is clear from the figures that the predicted maximum stresses in the disc groove occurred at the first serration coinciding with those of the blade root. High stresses are also predicted at the last groove serration. The maximum stresses in the disc groove serrations are equivalent to approximately 60% of the maximum stresses in the blade root.

The displacement results for the disc segment are plotted in Figures 13 to 15. These displacements are consistent with the stress and displacement results described earlier.

4.0 CONCLUSIONS

From the results of this preliminary investigation, it can be concluded that:

a) The two locations of high stress along the blade root (predicted previously in reference 2) are confirmed on one side. A third location of high stress at the middle of the blade root is predicted on the opposite side.

b) The predicted maximum stresses in the blade root occurred at the first serration at the locations of crack initiation.

c) The high stress in the blade root is primarily the result of the nature of the loading and the geometry of the blade. It is not due to the locking groove.

d) The modifications suggested by Parsons (removal of the locking groove) will not correct the situation of high stress.

e) The predicted maximum stresses in the disc groove occurred at the first serration coinciding with the areas of high stress in the blade root. High stresses are also predicted at the last groove serration.

f) The maximum stresses in the disc groove are equivalent to approximately 60% of the maximum stresses in the blade root. This is important since a disc failure has more severe consequences than a root failure in the top serration. (A root failure in a lower serration may result in a disc failure).

5.0 RECOMMENDATIONS

Based on these preliminary results, the following recommendations can be drawn:

a) Removal of the locking groove should not be carried out. As shown in the previous analysis (2), this will result in higher stresses.

b) Although other fixes, such as increasing the fillet radius in the top serration, may reduce local stresses, they should not be carried out blindly. Detailed analyses should be carried out to determine the possible implications. For example, although it is desirable to decrease the probability of failure in the first serration, a failure at some other location may have more serious consequences.

c) A parametric analysis should be carried out to investigate the effect of the following:

- Bending loading acting on the blade vane
- Blade root/disc groove misfit
- Serration fillet radii
- Variation of platform thickness

This may lead to a better understanding of the inter-relationship between these parameters and provide help when assessing potential modifications.

d) A detailed 3-D analysis of the blade root/disc groove from another row should be carried out to study the effect of the different blade geometry and the different blade root/disc groove attachment.

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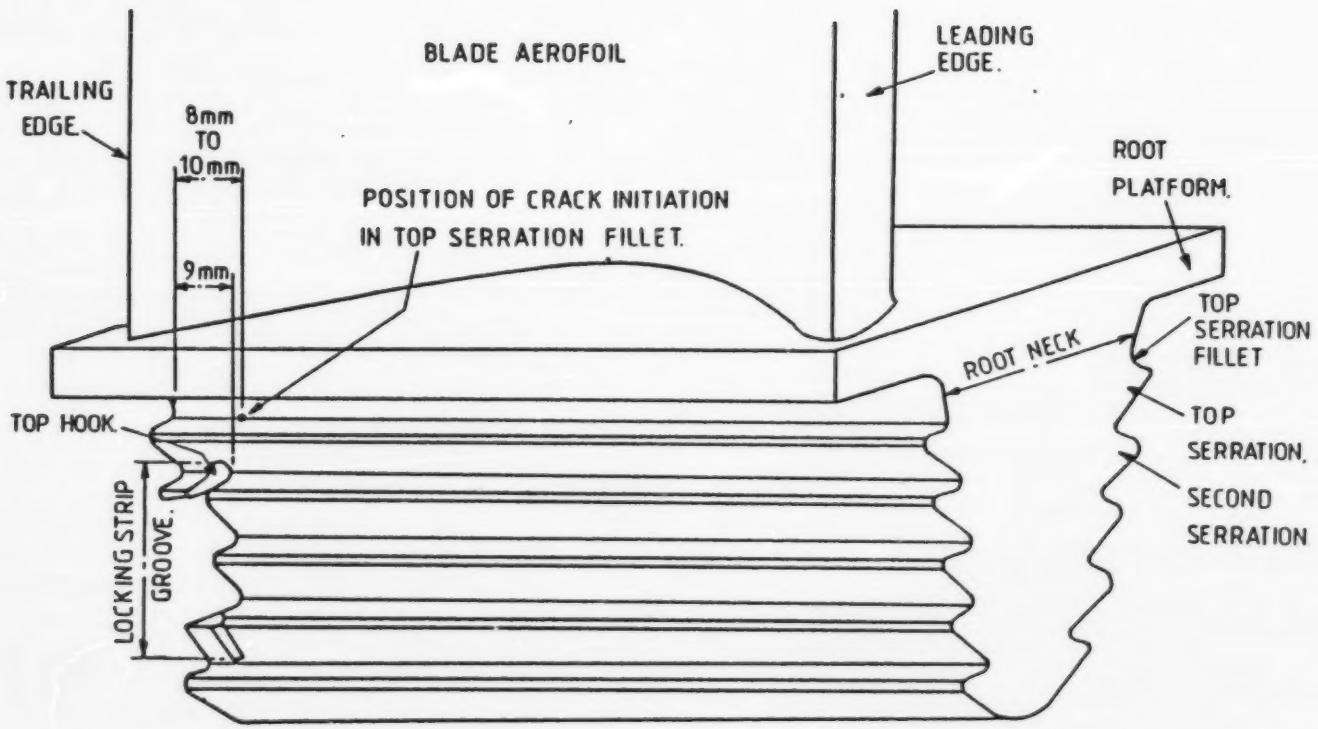

FIGURE 1.a

BLADE ROOT WITH LOCKING GROOVE
EXISTING DESIGN

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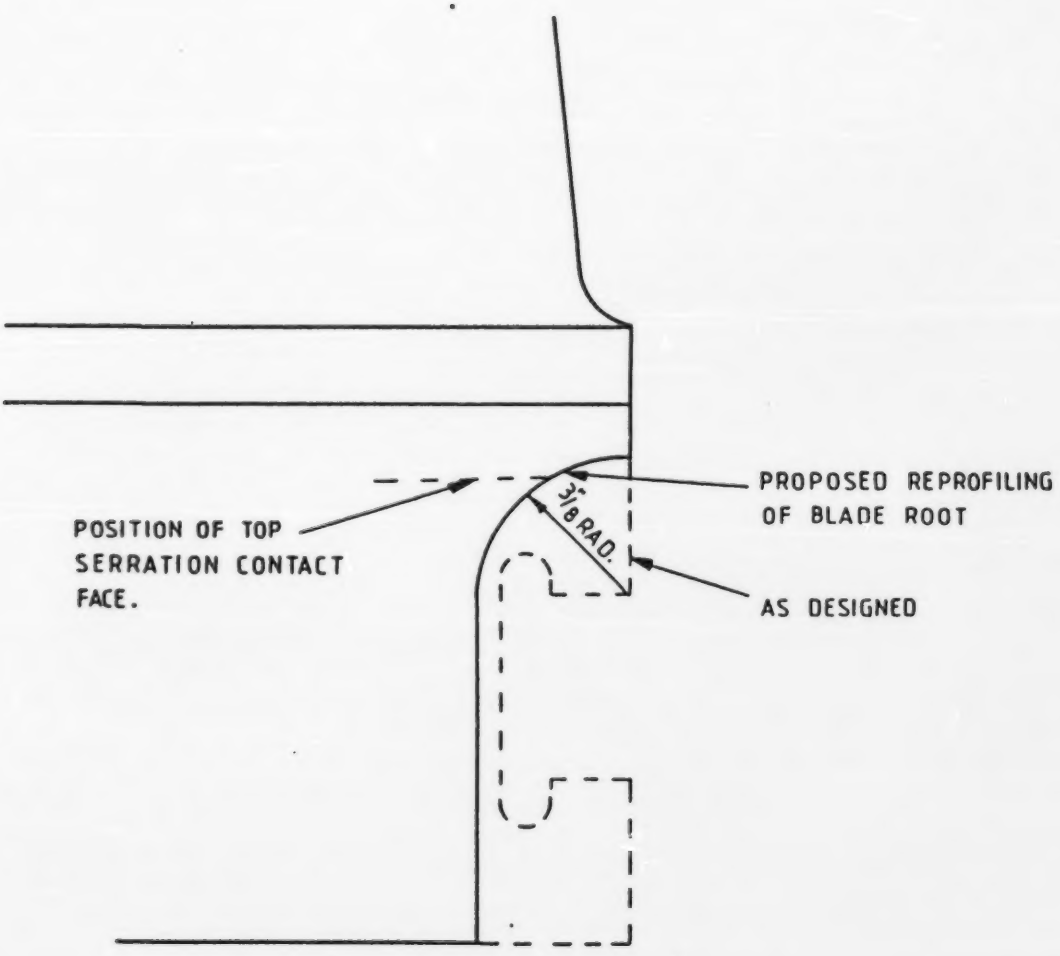

FIGURE 1.b

FIRST PROPOSED MODIFICATION TO LOCKING GROOVE

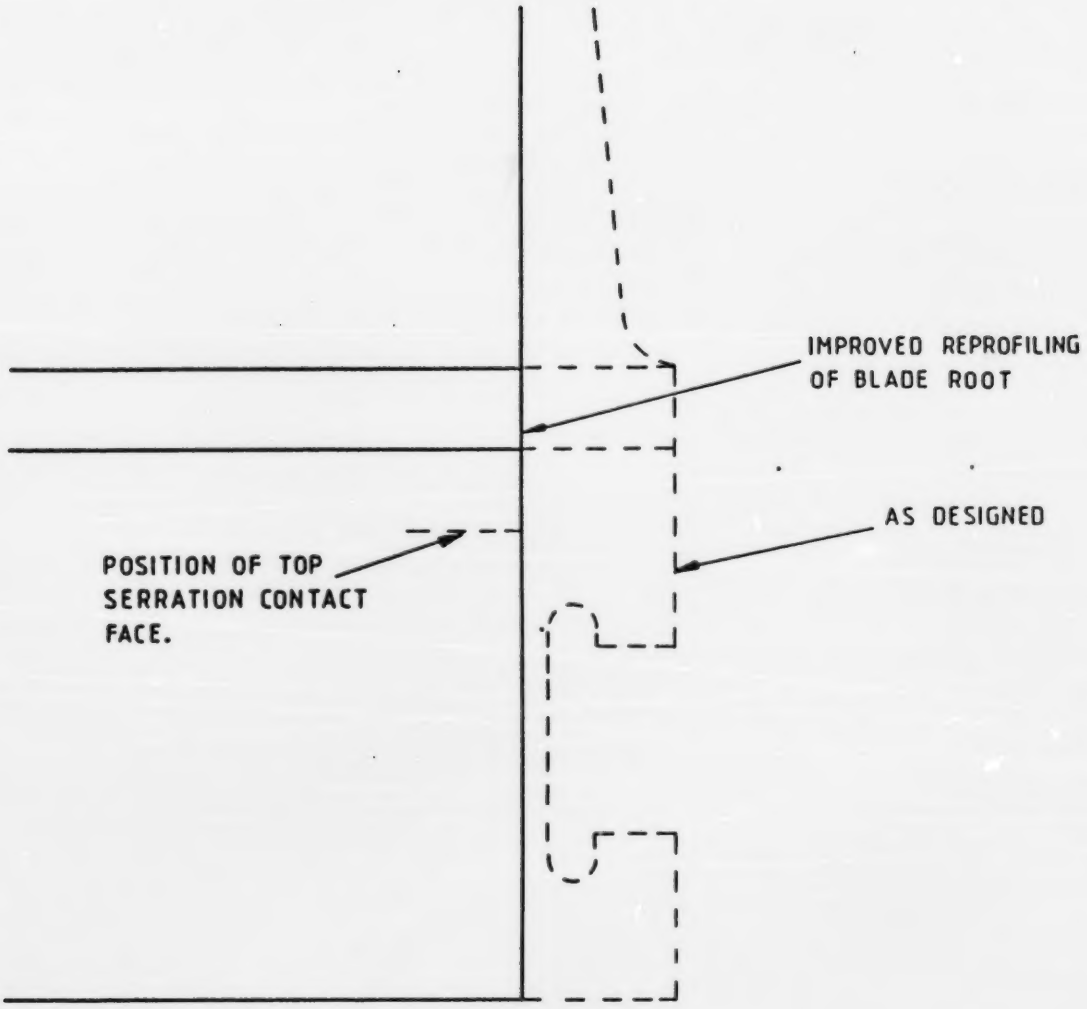

FIGURE 1.c

NEW IMPROVED MODIFICATION TO LOCKING GROOVE

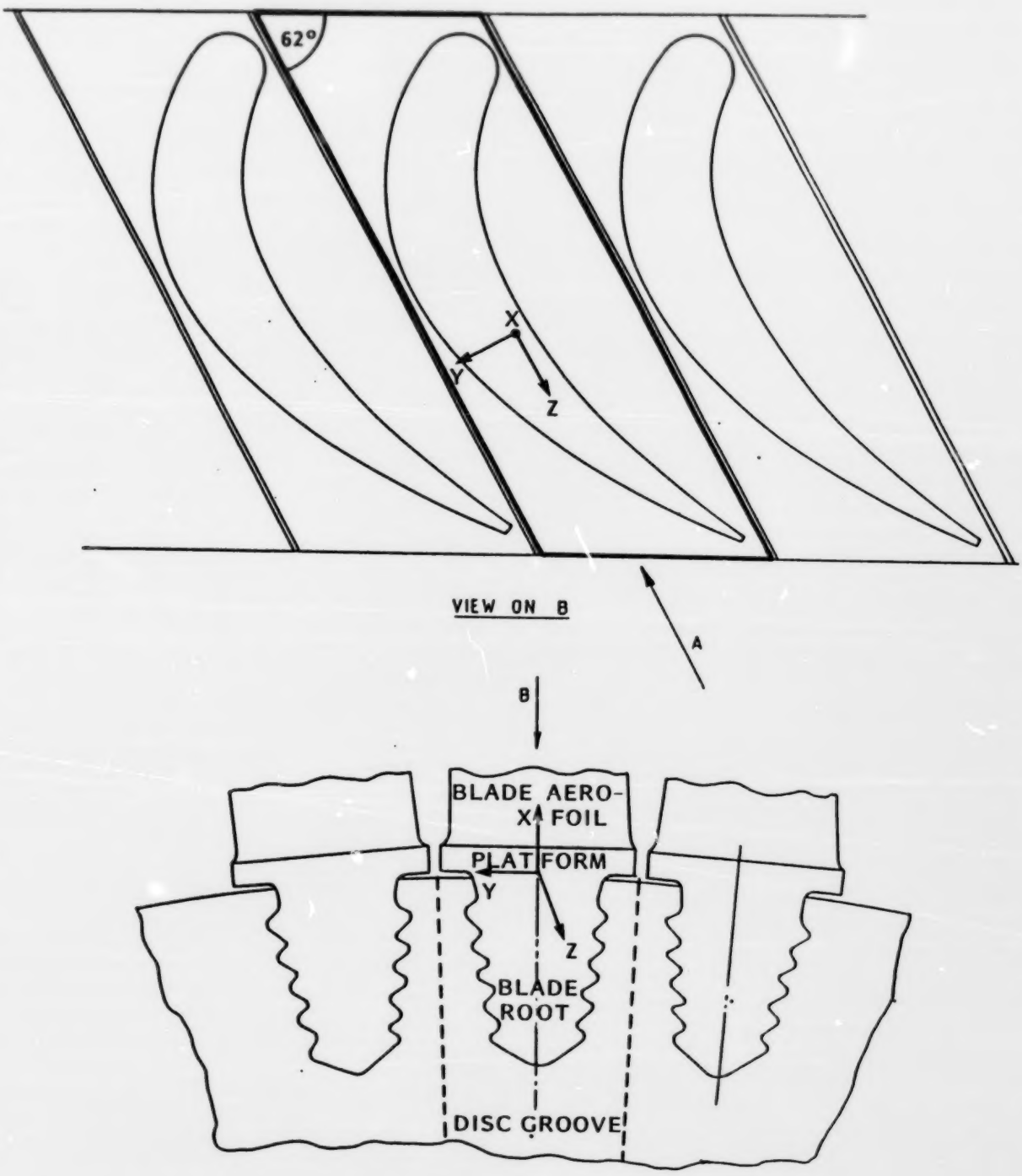

FIGURE 2

TURBINE BLADE/DISC ATTACHMENT
GENERAL LAYOUT

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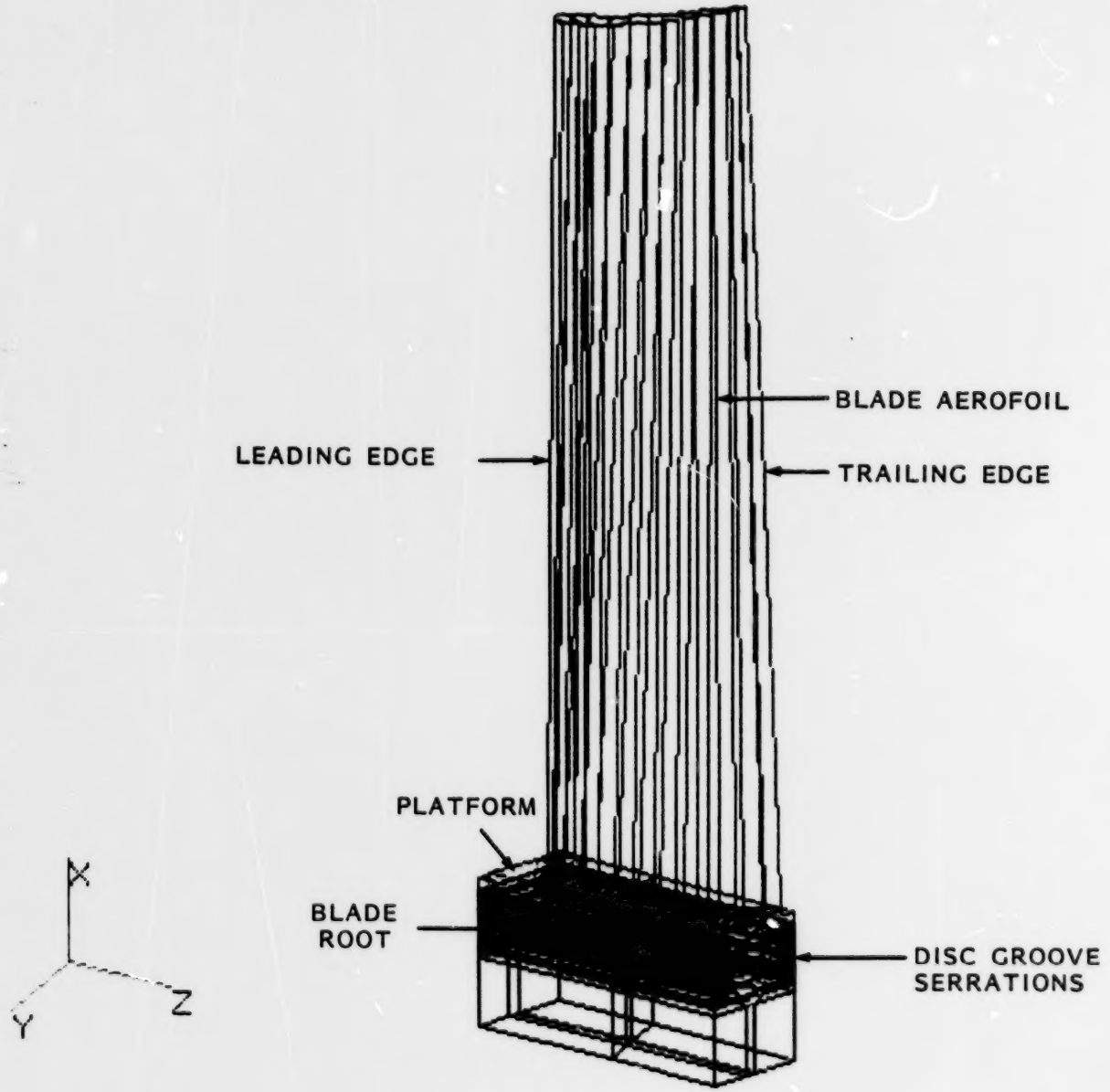

FIGURE 3

TURBINE BLADE/DISC GEOMETRY USED TO CREATE THE FEM

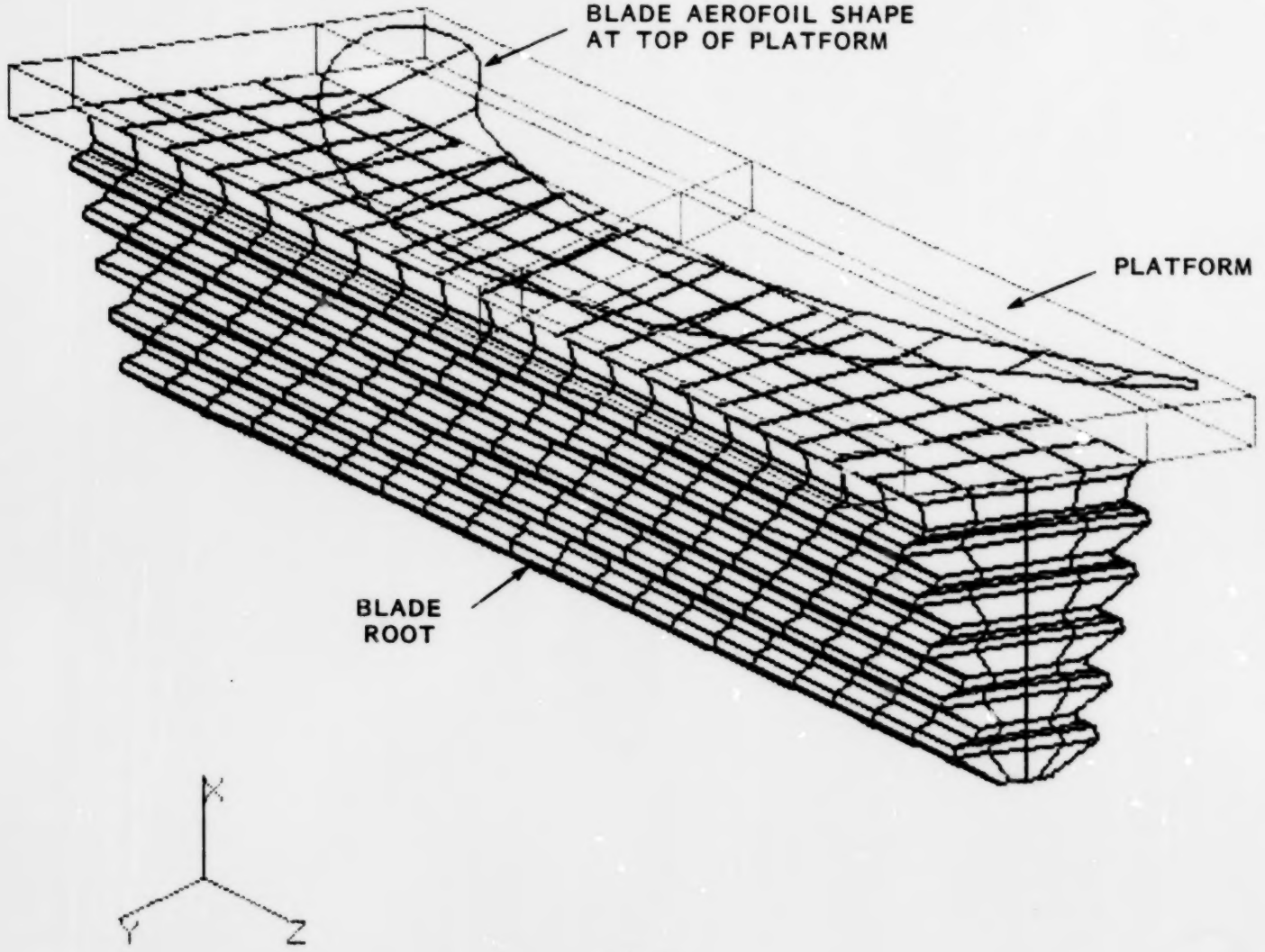

FIGURE 4

FINITE ELEMENT MODEL - BLADE ROOT

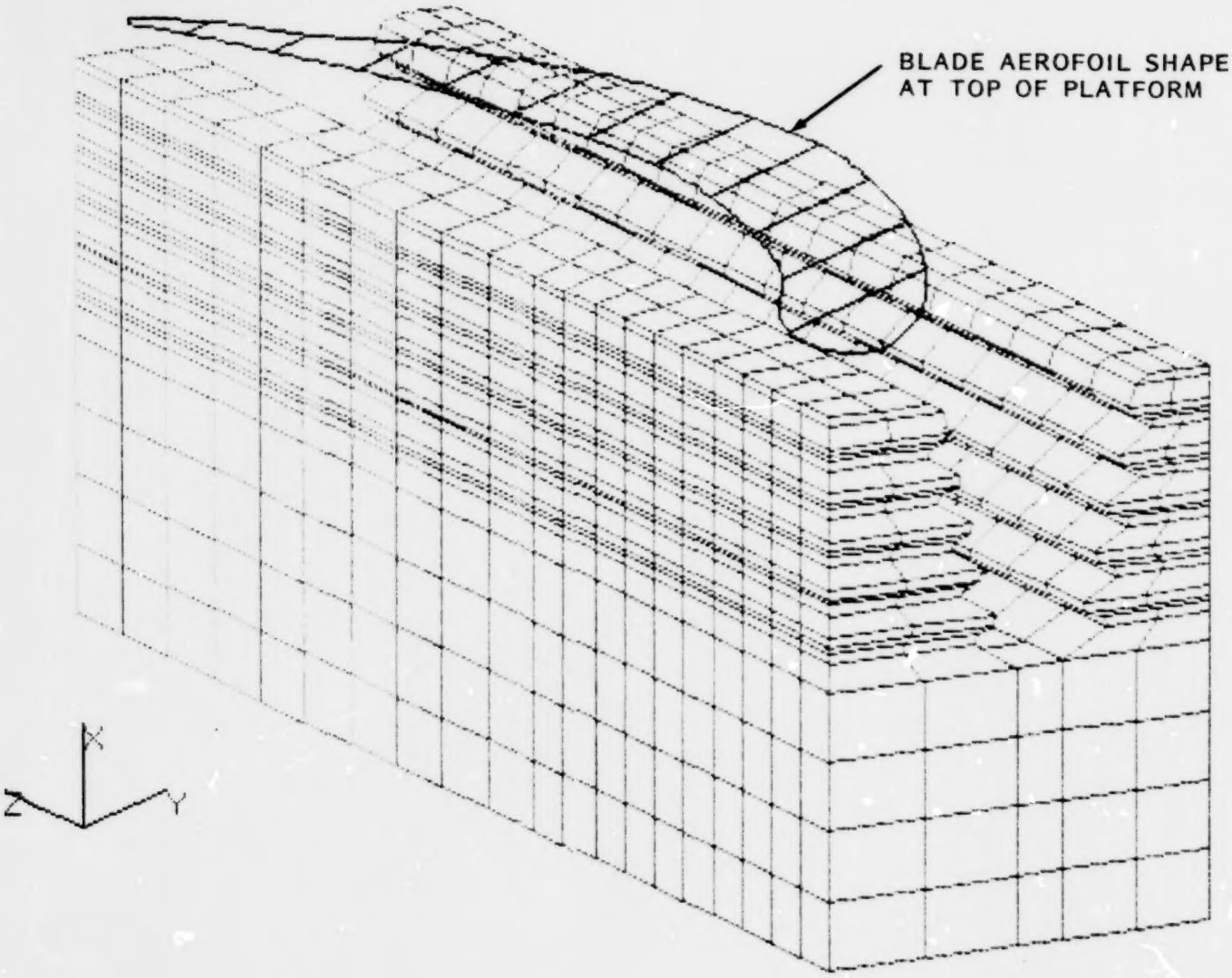

FIGURE 5

FINITE ELEMENT MODEL - DISC GROOVE SERRATIONS

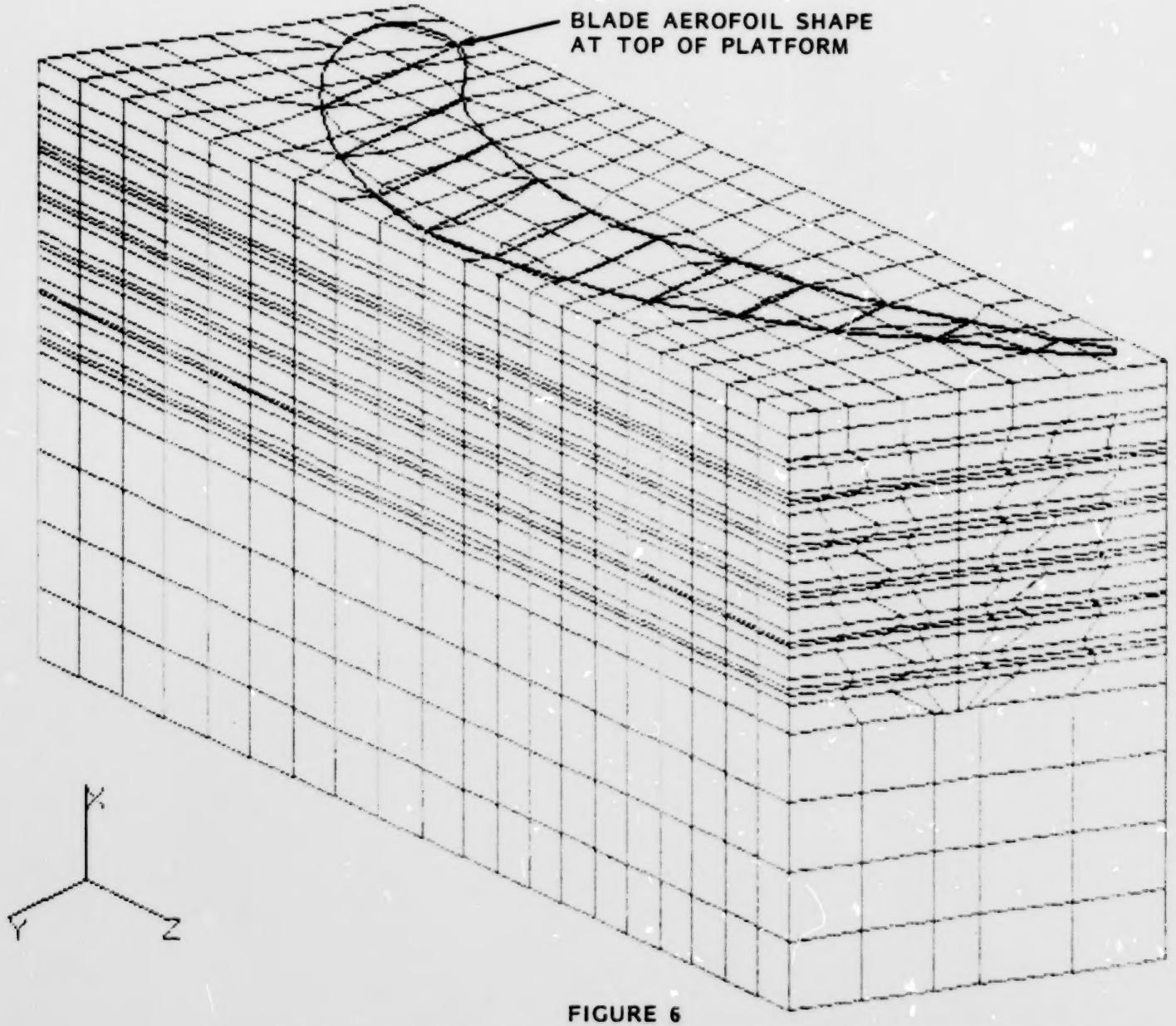

FIGURE 6

FINITE ELEMENT MODEL - BLADE ROOT/DISC GROOVE ATTACHMENT

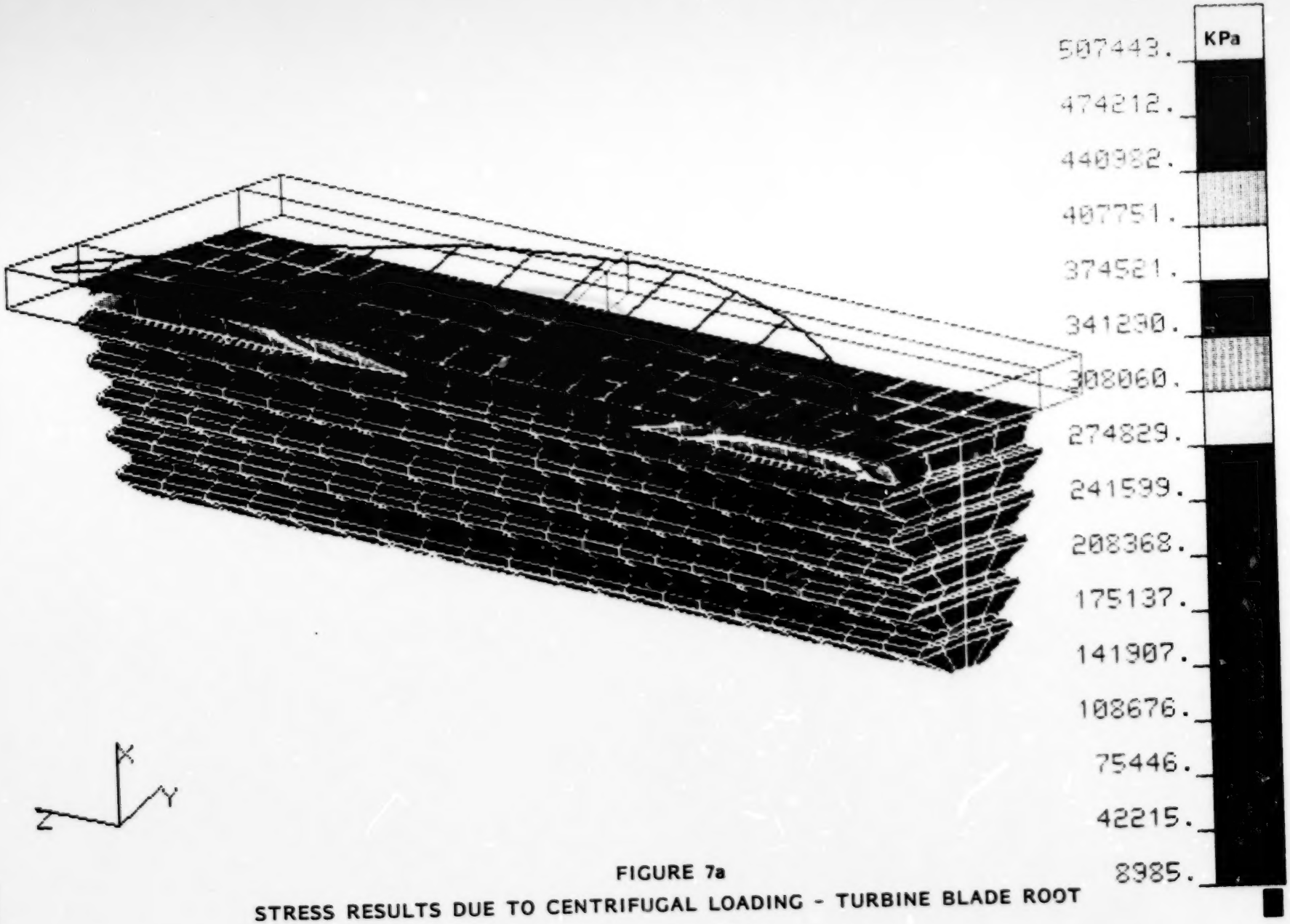

FIGURE 7a

STRESS RESULTS DUE TO CENTRIFUGAL LOADING - TURBINE BLADE ROOT

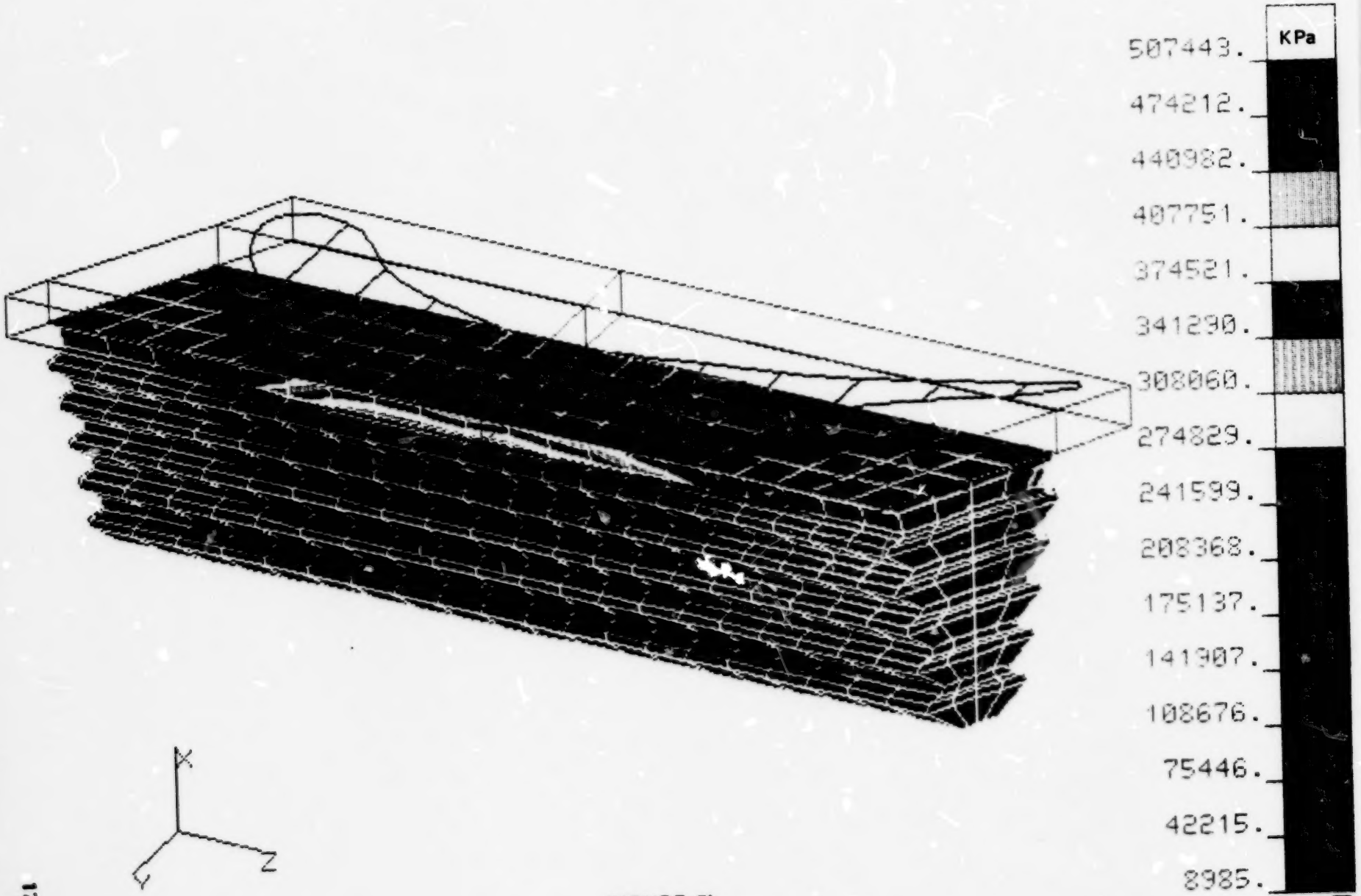

FIGURE 7b

STRESS RESULTS DUE TO CENTRIFUGAL LOADING - TURBINE BLADE ROOT

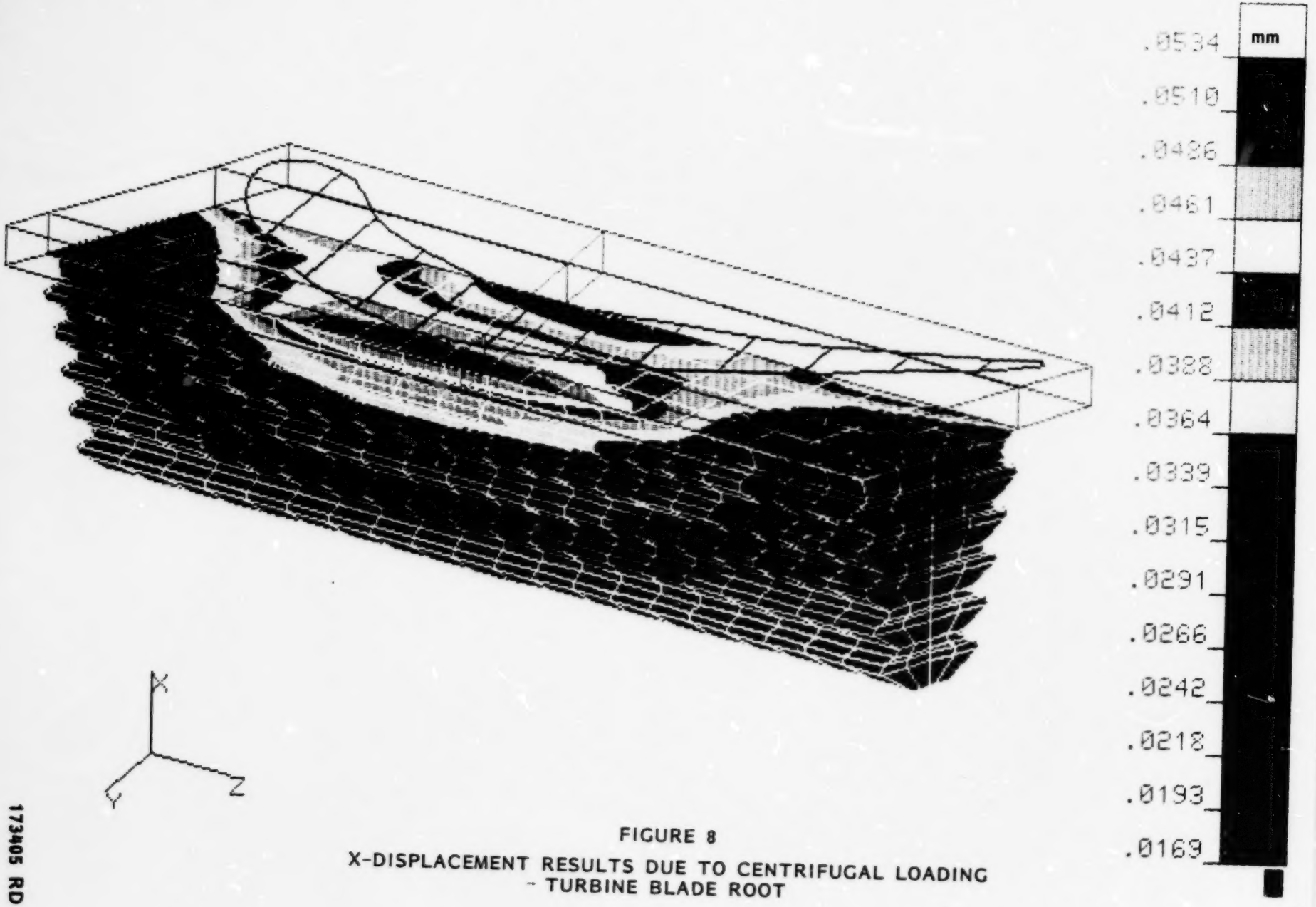

FIGURE 8
X-DISPLACEMENT RESULTS DUE TO CENTRIFUGAL LOADING
- TURBINE BLADE ROOT

173405 RD

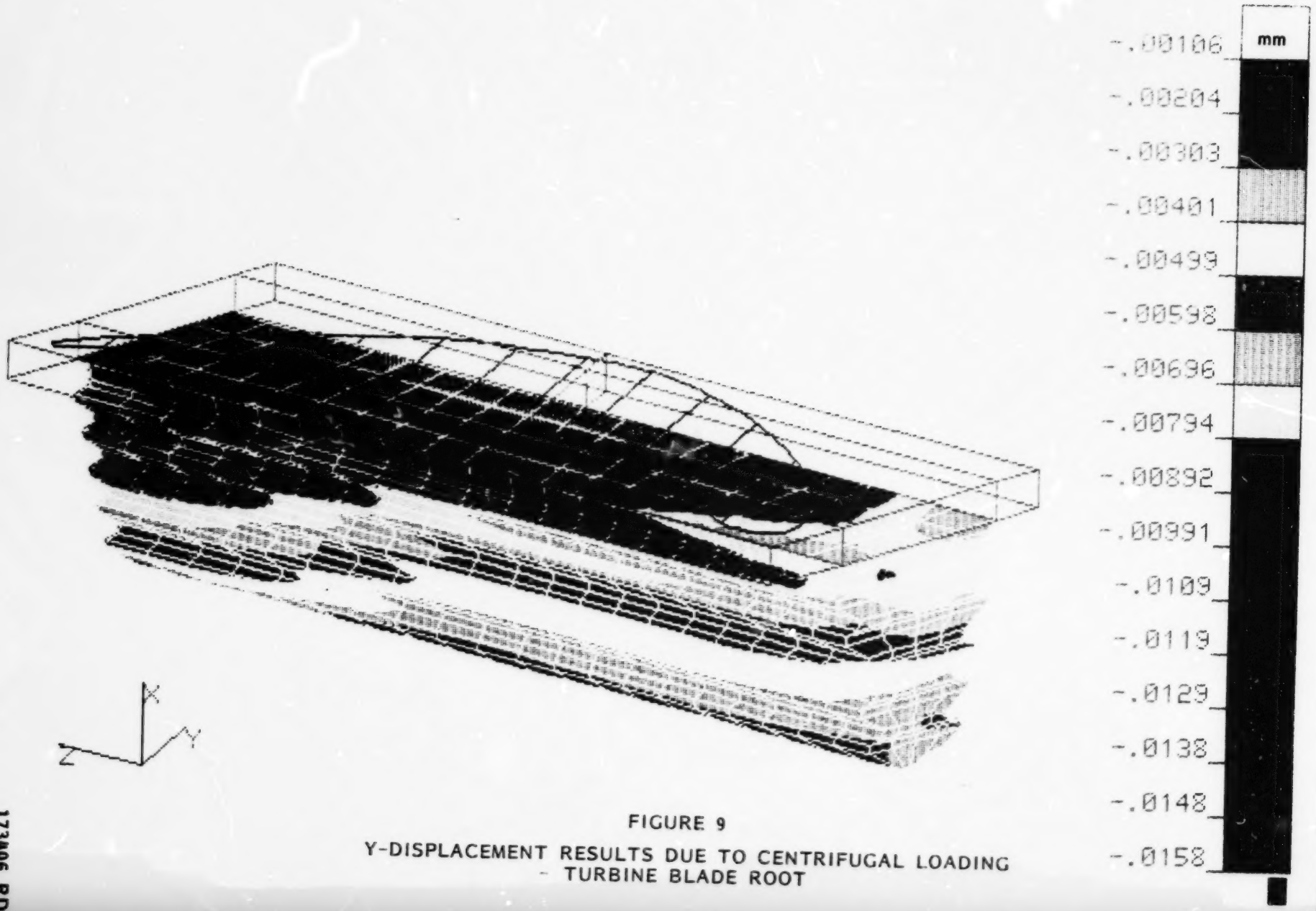

FIGURE 9

Y-DISPLACEMENT RESULTS DUE TO CENTRIFUGAL LOADING - TURBINE BLADE ROOT

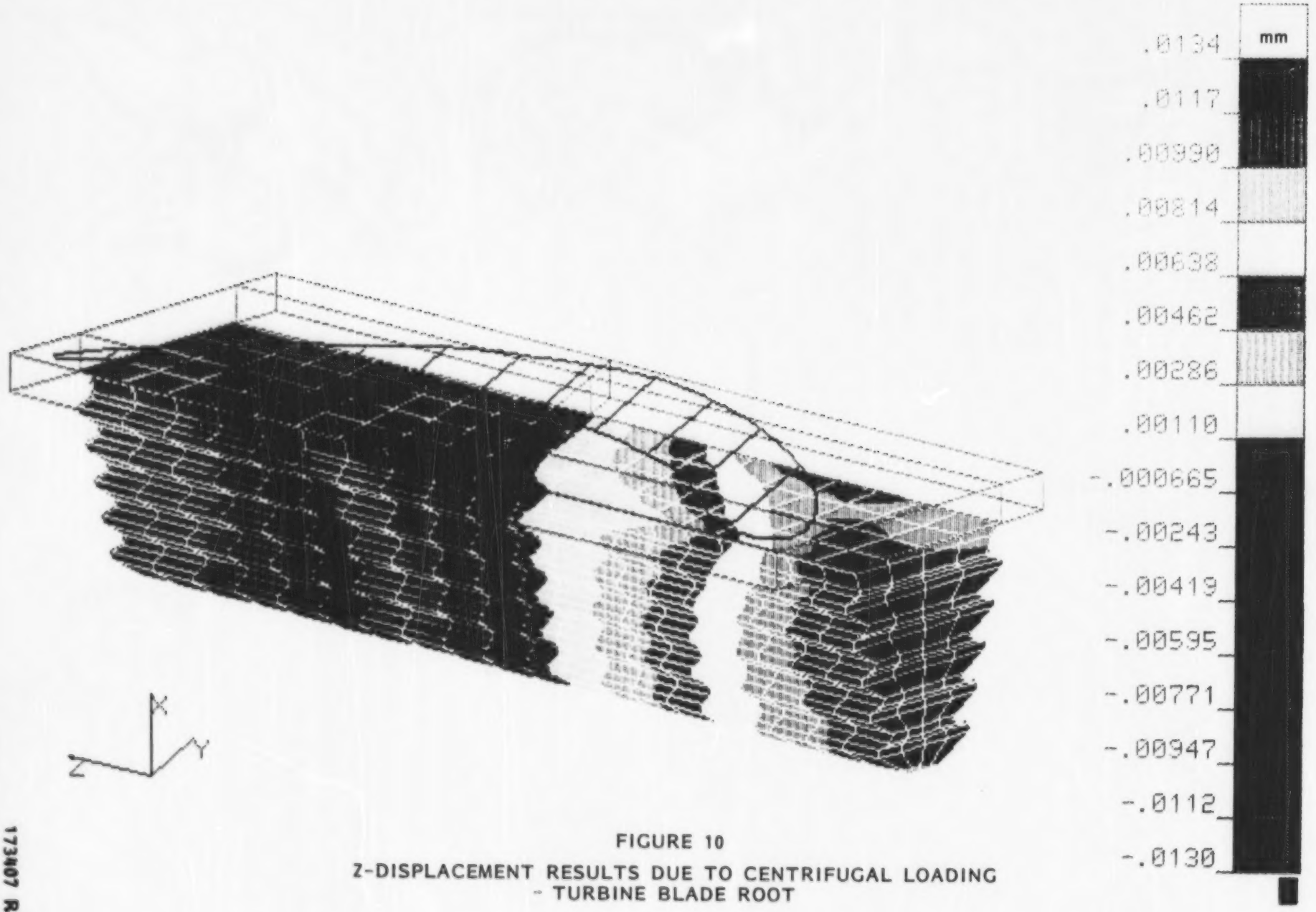

FIGURE 10

Z-DISPLACEMENT RESULTS DUE TO CENTRIFUGAL LOADING
- TURBINE BLADE ROOT

173407 RD

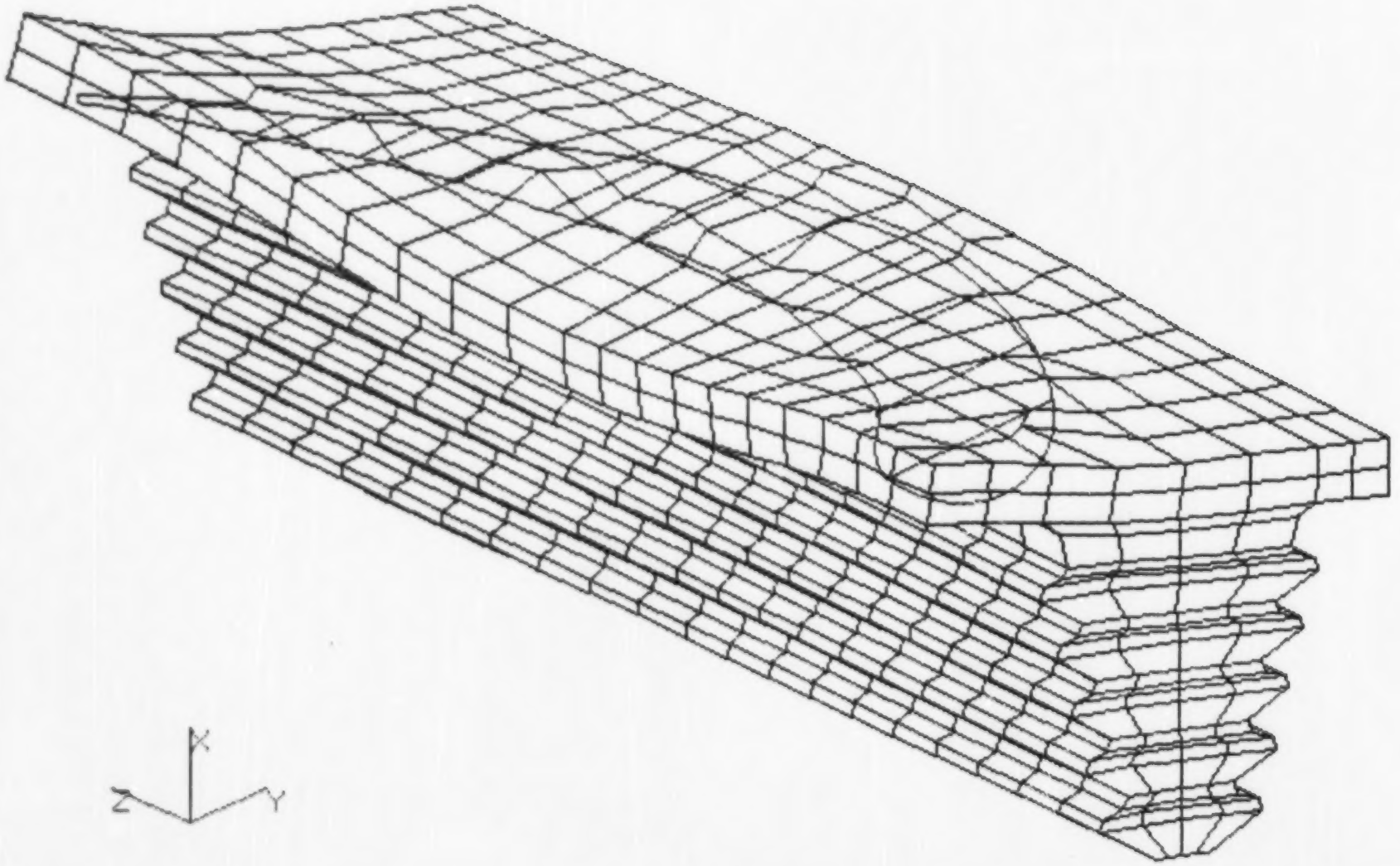

FIGURE 11

DEFORMED SHAPE DUE TO CENTRIFUGAL LOADING
- TURBINE BLADE ROOT

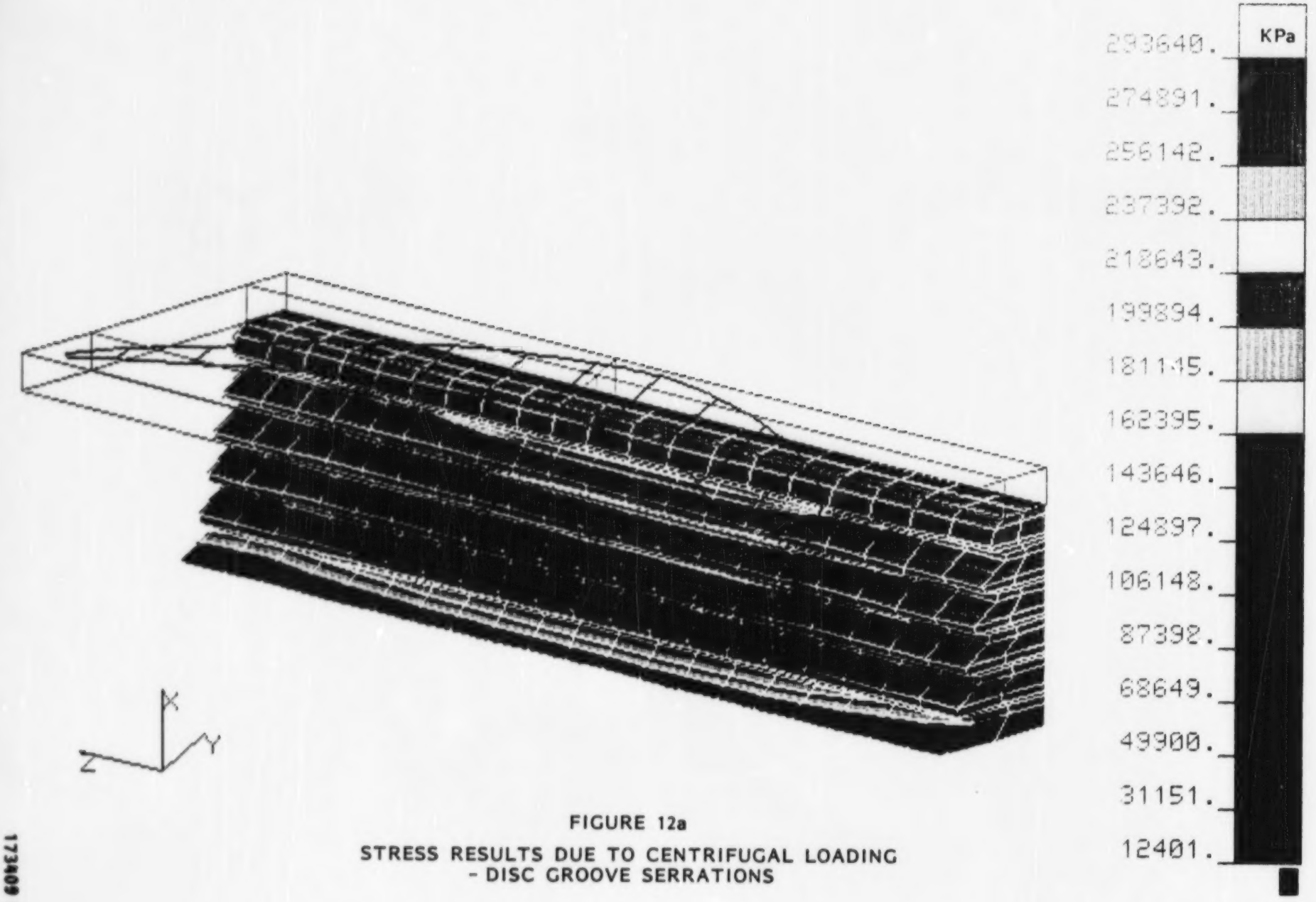

FIGURE 12a

STRESS RESULTS DUE TO CENTRIFUGAL LOADING
- DISC GROOVE SERRATIONS

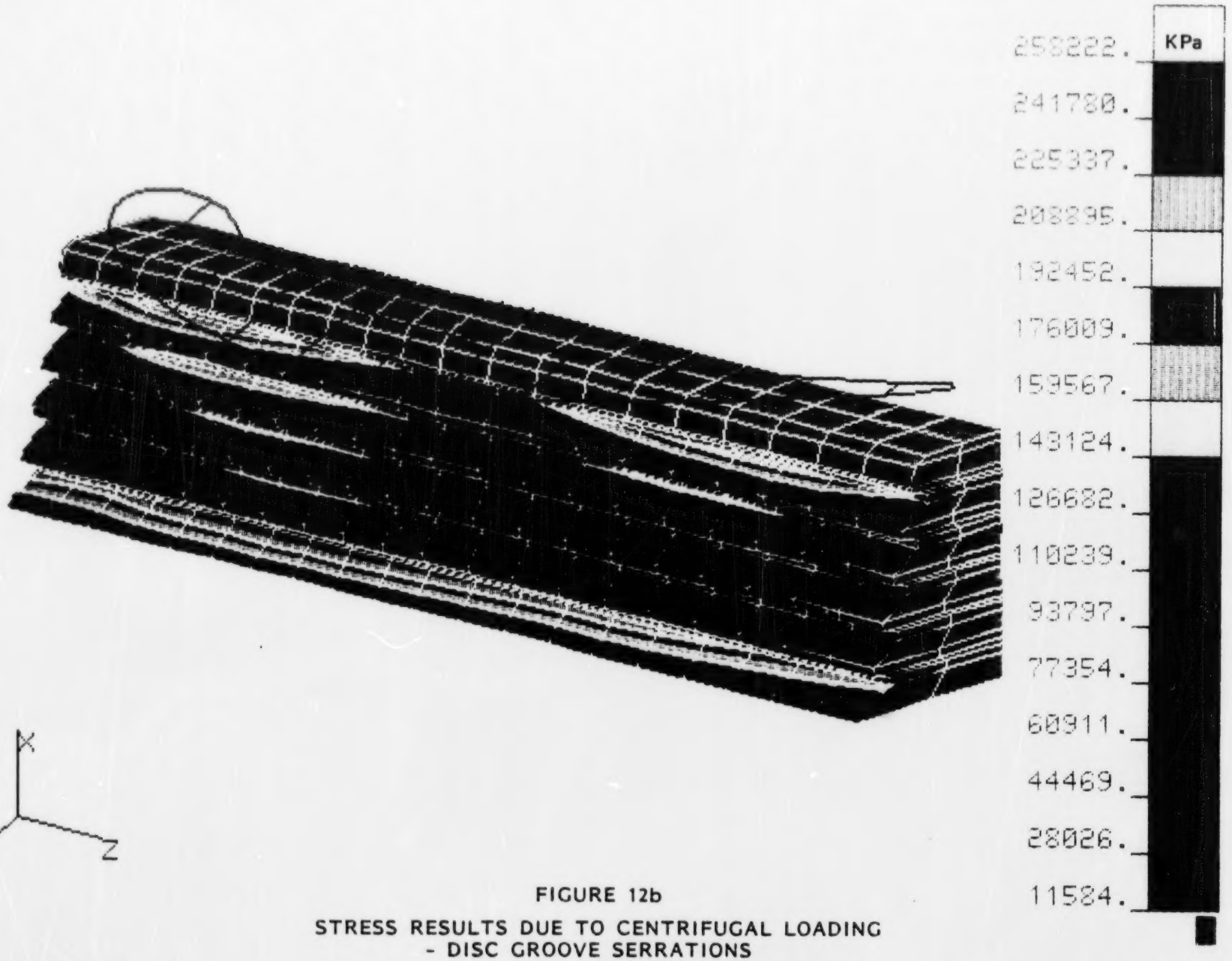

FIGURE 12b

STRESS RESULTS DUE TO CENTRIFUGAL LOADING
- DISC GROOVE SERRATIONS

173410 RD

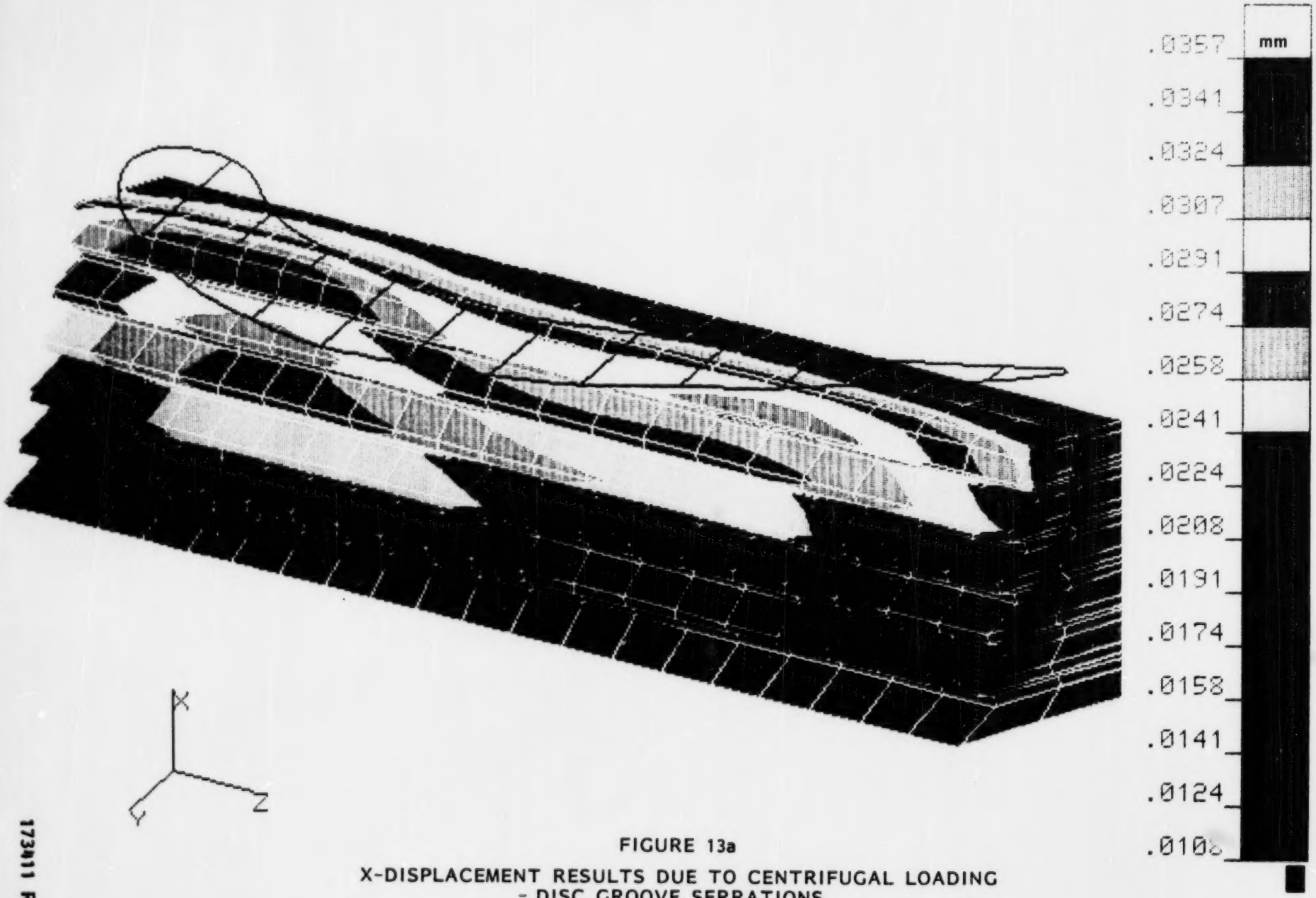

FIGURE 13a

X-DISPLACEMENT RESULTS DUE TO CENTRIFUGAL LOADING
- DISC GROOVE SERRATIONS

173811 RD

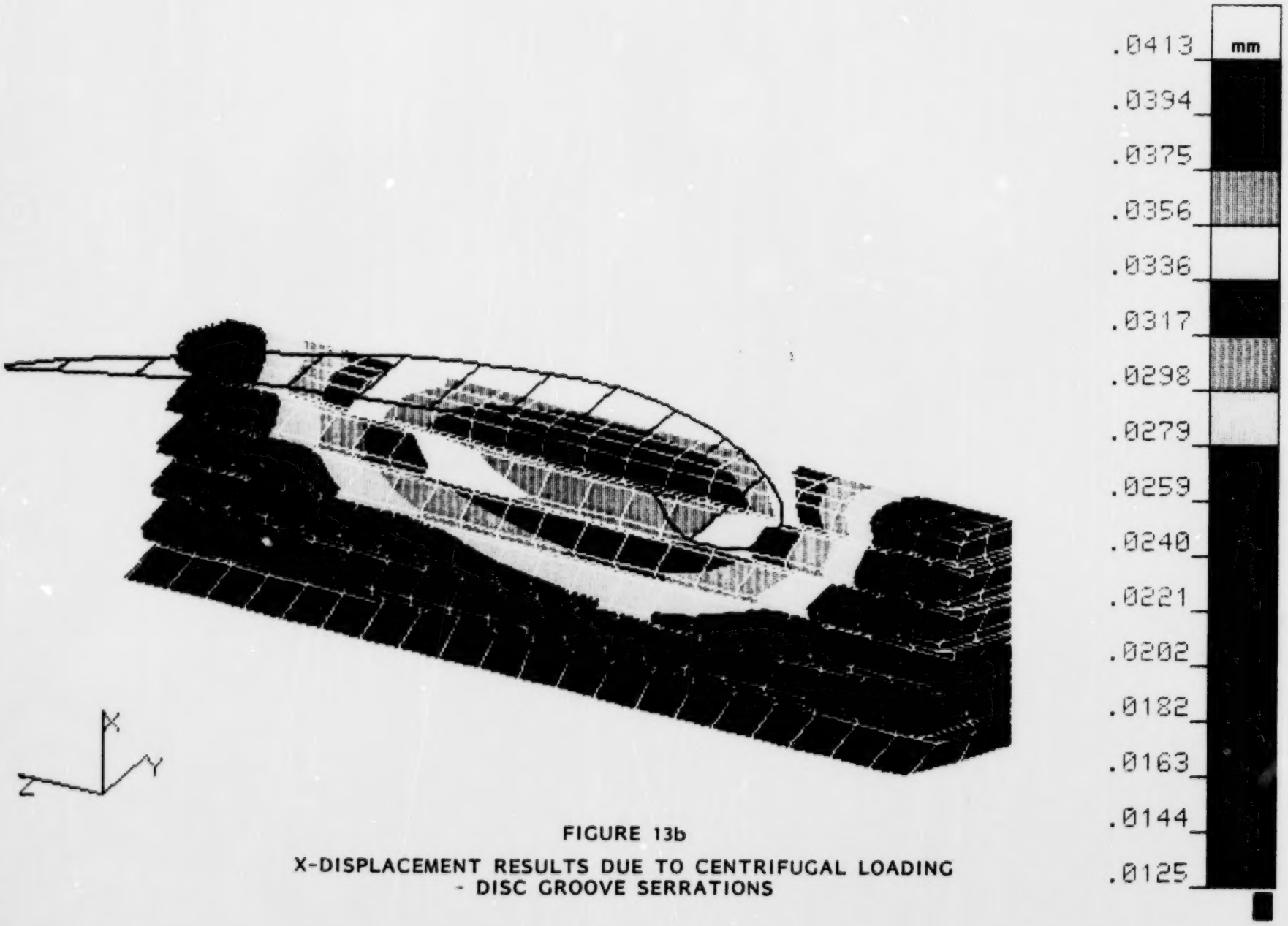

FIGURE 13b

X-DISPLACEMENT RESULTS DUE TO CENTRIFUGAL LOADING
- DISC GROOVE SERRATIONS

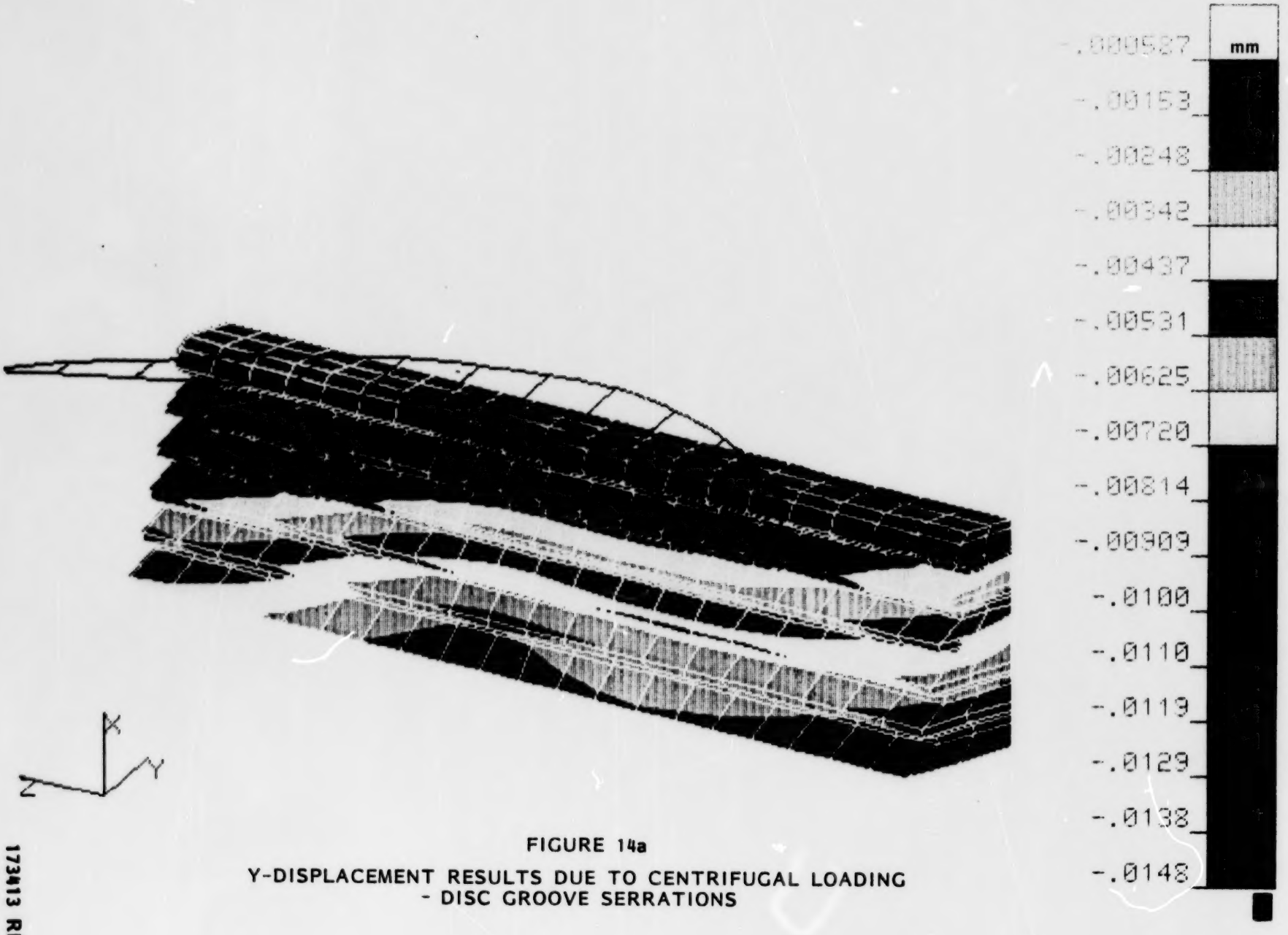

FIGURE 14a

Y-DISPLACEMENT RESULTS DUE TO CENTRIFUGAL LOADING
- DISC GROOVE SERRATIONS

173413 RD

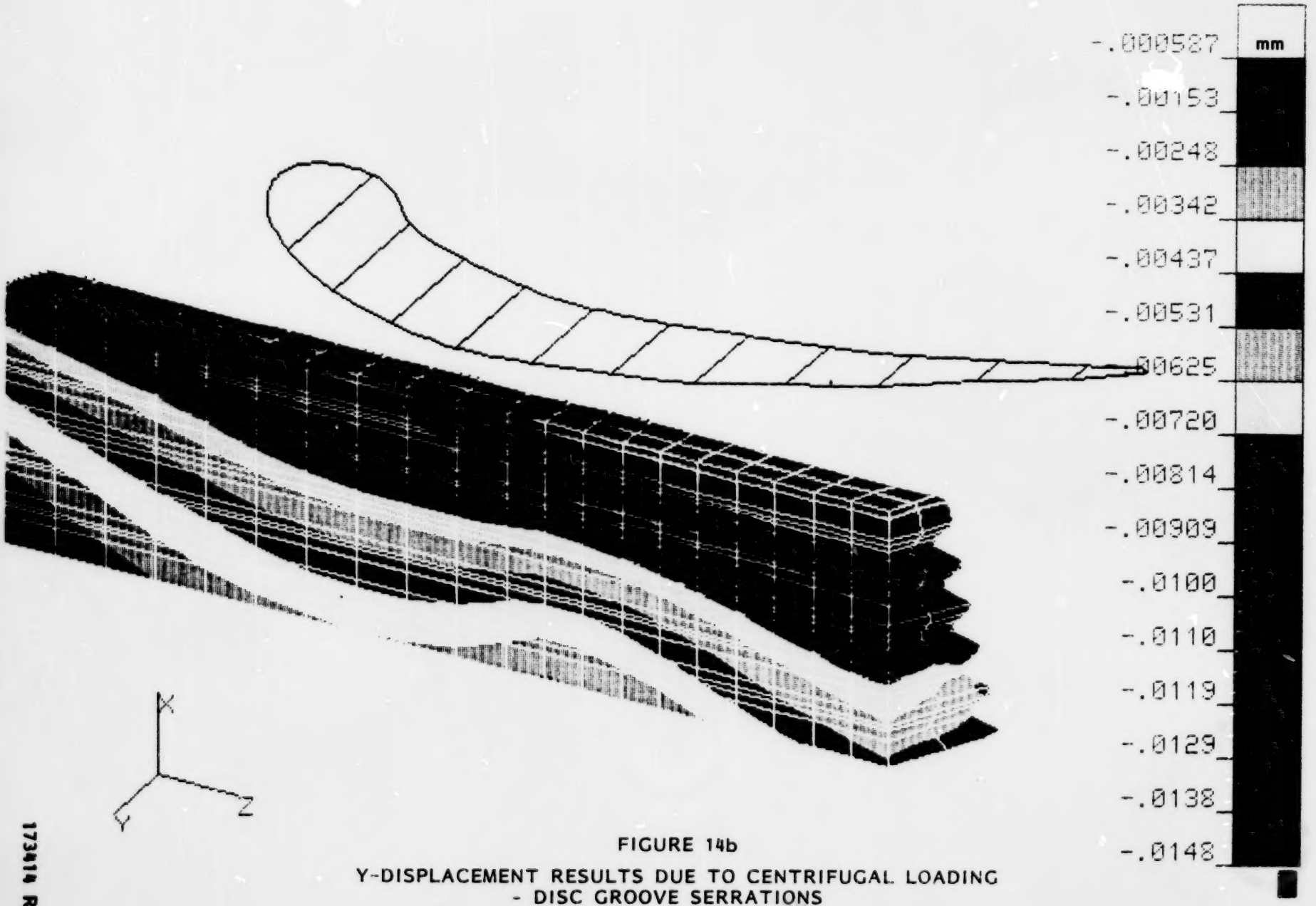

FIGURE 14b

Y-DISPLACEMENT RESULTS DUE TO CENTRIFUGAL LOADING
- DISC GROOVE SERRATIONS

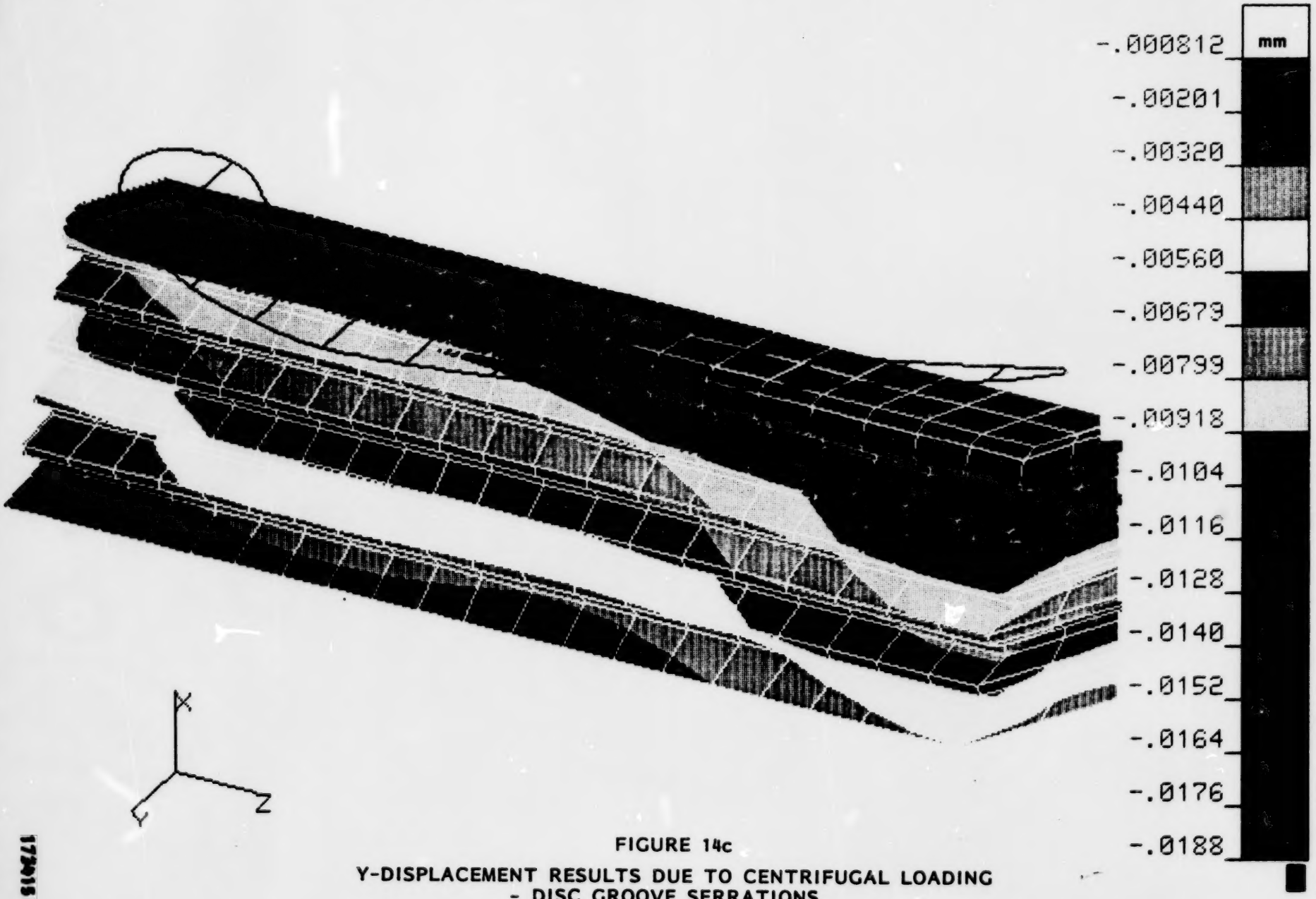

FIGURE 14c

Y-DISPLACEMENT RESULTS DUE TO CENTRIFUGAL LOADING
- DISC GROOVE SERRATIONS

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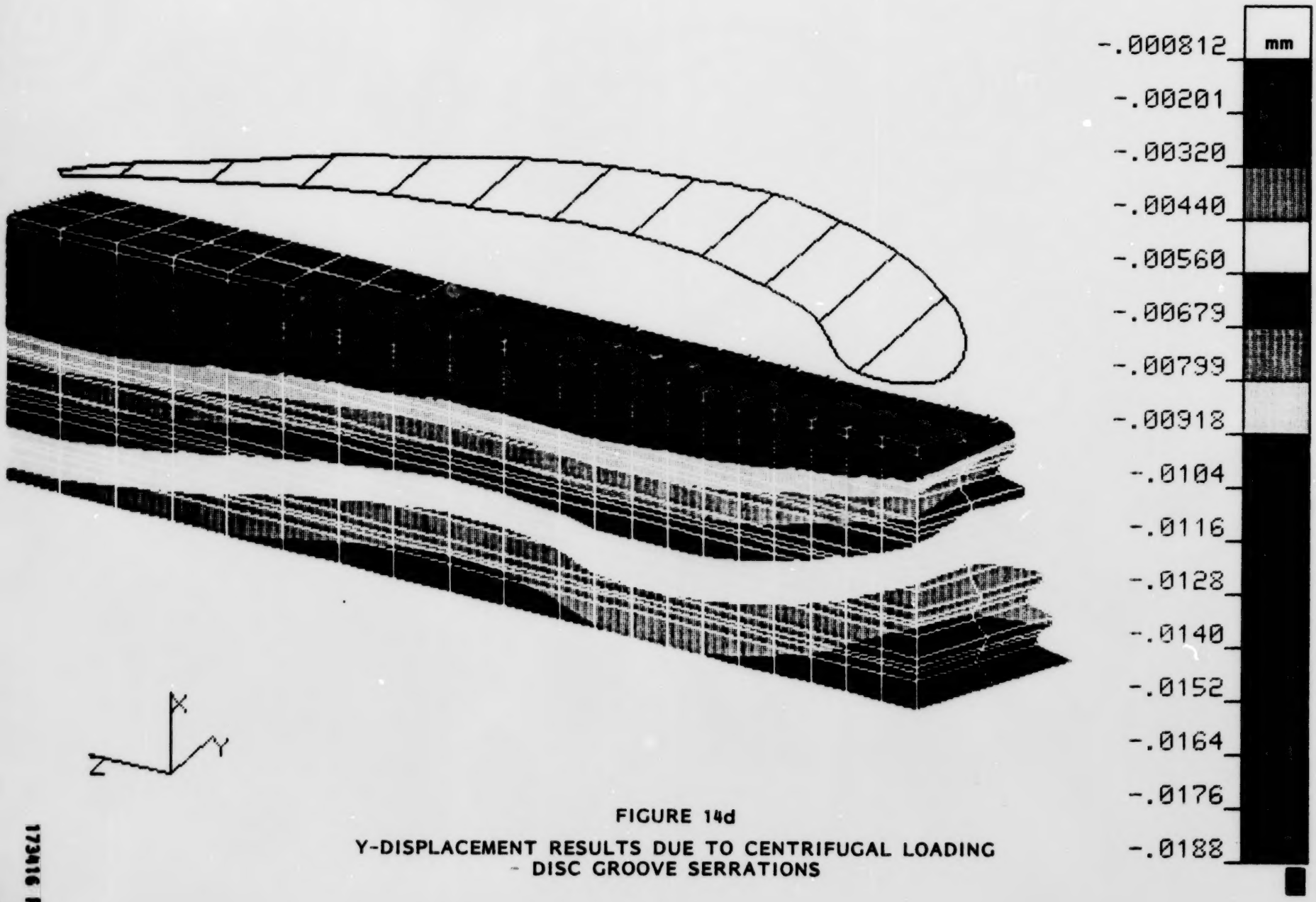

FIGURE 14d

Y-DISPLACEMENT RESULTS DUE TO CENTRIFUGAL LOADING
- DISC GROOVE SERRATIONS

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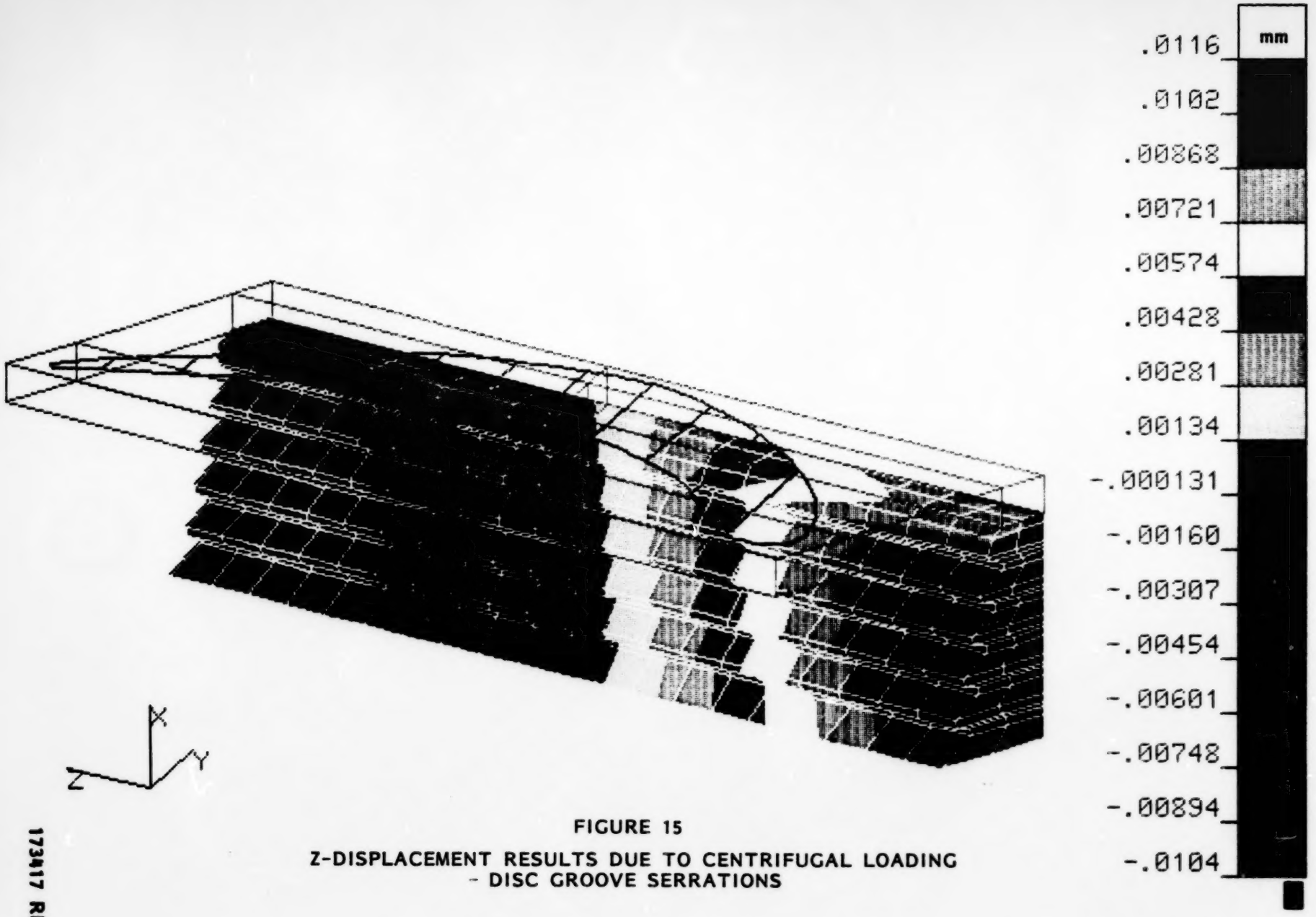

FIGURE 15

Z-DISPLACEMENT RESULTS DUE TO CENTRIFUGAL LOADING
- DISC GROOVE SERRATIONS

173417 RD

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